TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909

INCORPORATED 1930

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VOLUME XIV
No. 2 — 1949

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

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The Gas Arc

A New Light Source

By J. N. ALDINGTON, B.Sc., Ph.D., F.R.I.C., F.Inst.P. (*Fellow*)

Summary

The term "Gas Arc" has been applied to a recently developed range of xenon-filled discharge tubes operated under conditions which cause them to emit radiation of sunlight quality. The radiation from the Gas Arc is characterised by an intense continuum extending from the ultra violet through the visible region into the infra red.

An introductory section is followed by some considerations of the factors which influenced the development of this new source. The luminous and other characteristics of the Gas Arc in its present form are given, and it is shown that a 5-kw. xenon-filled lamp has an initial efficiency of 25-30 l./w.

The simple circuit arrangement necessary for the ignition and operation of Gas Arc lamps is described.

The concluding sections deal with some of the latest developments in this field and with an examination of possible applications.

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(1) Introduction

In October, 1947, the successful development was announced of a water-cooled Gas Arc which emitted radiation of sunlight quality: the lamp was the culmination of many years of work on glow and arc discharges through gases and metallic vapours. It is important to realise that the Gas Arc in its present form could not have been produced without the special techniques for sealing

The author is with Siemens Electric Lamps and Supplies, Ltd., Preston. The manuscript of this paper was first received on July 24, 1948, and in its revised form on October 19, 1948. The paper was presented at a meeting of the Society on December 14, 1948.

high current conductors through quartz, and the various electrode developments which have been referred to in previous publications before this Society and elsewhere.(1, 2)

It is considered that the new lamp represents a further stage in the evolutionary process which began with Hawksbee's observations of the glow discharge in 1709, and which has led in turn to the various practical discharge lamps which have already been described.(3, 4, 5, 6, 7) The present paper is devoted to discussing the evolution of the Gas Arc. A description of the first practical lamp is prefaced by a general section dealing with some of the more interesting principles which guide a development of this nature, and later sections contain data on the present experimental types. The paper concludes with some consideration of possible developments and applications.

(2) General Theory

(2.1) Selection of Gas or Vapour Filling

The radiation which results from the discharge of electricity through a gas is in general characteristic of the particular gas. In a mixture of gases or of metallic vapours the radiation may largely or entirely result from excitation processes occurring in the element of the mixture which has the minimum ionisation potential. These statements are basically true for low current discharges through gases or vapours at low pressure. Under conditions of higher pressure and current density, however, more complex discharge phenomena occur, and simultaneous excitation of the spectra of several components of a gaseous mixture can occur, particularly if there is some similarity in the ionisation constants of the various components. In general, however, the radiation from practically all electric discharge lamps is characteristic of one component only of the gas or vapour in the lamp. This is true moreover of lamps in which the partial pressures of the various components vary quite widely, as is shown in Table 1.

Table 1.

Dominant Spectra of Discharge Lamps.

Gaseous Component.	Metallic or other Component.	Dominant Spectrum.
Neon 5 mm.	—	Neon
Neon 5 mm.	Mercury 0.01 mm.	Mercury
Neon 5 mm.	Argon 2.0 mm.	Argon
Neon 5 mm.	Sodium 0.01 mm.	Sodium
Argon 5 mm.	Mercury 0.01 mm.	Mercury

Studies of the principal wave-lengths at which radiation is emitted from the electrically excited atom have been in the past largely used to assess the potentialities of any particular element as a source of light. Some typical data are given in Table 2, and it is apparent that certain elements appear more likely to be useful than others, especially those in which most or all of the sensitive spectral lines lie in the visible region between 4,000Å and 7,000Å. Such data, however, contain no information respecting the proportion of the total radiant power emitted at each wavelength. Without knowledge of this vitally important aspect of the characteristic of an excited atom it is not possible to finally assess whether or not a particular element will become important in discharge lamp developments.

Table 2.

Emission Spectra of Metallic Vapours.

Aluminium (arc).	Cadmium (arc).	Caesium (CsCl in flame).	Lithium (LiCl in flame).	Mercury (Mercury lamp).	Sodium (NaCl in flame).	Thallium ($TlCl_3$ in flame).	Zinc (arc in vacuo).
3962 Å	4799.9 Å	4555 Å	3232 Å	4046 Å	5890 Å	4525 Å	4912 Å
6232 Å	5085.8 Å	4593 Å	4603 Å	4358 Å	5896 Å	5563 Å	4925 Å
6243 Å	6438.5 Å	8521 Å	6103.6 Å	5790.7 Å	—	5589 Å	6103 Å
—	—	8943 Å	6707.8 Å	5769.6 Å	—	5799 Å	—
—	—	—	—	5460.7 Å	—	—	—

Emission Spectra of Gases.

Low Current Discharge Through 2-4 mm. Pressure.

Hydrogen.	Helium.	Argon.	Krypton.	Xenon.
4102 Å	3188 Å	4159 Å	5570 Å	4500 Å
4340 Å	3889 Å	4192 Å	5871 Å	4624 Å
4861 Å	4471.5 Å	4198 Å	—	4671 Å
6563 Å	4875.6 Å	4201 Å	—	—
—	—	4259 Å	—	—
—	—	4703 Å	—	—
—	—	6031 Å	—	—

These data on the emission spectra of various gases and metallic vapours have been obtained from observations on a variety of sources, including the electric arc, the low current discharge, and flames in open air or in some partially confined space (8, 9, 10, 11). In general, whatever the excitation conditions the relative intensities of the various spectral lines will be governed by the particular conditions of excitation and must not be taken as fundamental of the element under consideration.

Such data have been valuable in much of the earlier work on electric discharge lamps, for it was found quite early that the normal spark spectrum or flame spectrum was produced for most elements capable of excitation in the low-pressure discharge tube, and very broadly the relative brightness of the principal spectral lines appeared to be in the same order as had been obtained in the flame or open spark.

It is necessary, however, to remind ourselves that the physical conditions which obtain in the discharge tube may exert a dominating influence on the properties of the resultant radiation. A well-known example is the radiation from the electrically excited mercury atom. At low pressures the radiation is largely confined to the 2537Å region, but at higher pressures an increasing proportion of the emitted energy occurs in the visible region. From this and similar examples we are reminded that it is necessary to be cautious in considering published spectral data before any particular element is rejected as

a possible source of visible light. The published data may have been obtained under one set of conditions, while another set of conditions not yet investigated may give a very different picture of the potentialities of the element.

Existing techniques have so far allowed the study of only relatively few elements over a wide range of pressure and current density. Perhaps most is known about mercury vapour and very little about the rare gases. For example, the spectrum of argon appears very unpromising if we study published data, and the efficiency of low-pressure argon-filled tubes is very low. Several years ago, however, the author and his colleagues, among others, observed that at higher pressures and at very high current densities argon could be excited to produce an intense white light of high efficiency. The possibilities with krypton and xenon appeared even more favourable, and it was decided to make a large-scale investigation.

In essence the problem was to determine whether, with available materials, it was possible to excite the rare gases to such an extent that a continuous background spectrum was obtained, and secondly to determine whether under such conditions a practical lamp would result which would have a reasonably high efficiency. More particularly the investigation was directed to determining whether a simple form of lamp could be devised which would enable the desired radiation to be produced.

(2.2) Physical and Chemical Properties of Gas or Vapour Fillings

In considering the development of any discharge tube in which a particular gas or vaporisable metal is to be hermetically sealed there are further obvious but important factors of which it is necessary to take account. These include the vapour pressure characteristics of the element, whether it is normally liquid or solid, and its chemical reactivity. Some of these factors are illustrated in Table 3, which gives melting and boiling points of various elements together with some comments on their reactivity.

Table 3.

Characteristics of Some Elements.

Element.	Melting Point, deg. C.	Boiling Point, deg. C.	Chemical Reactivity.
Sodium ...	97.6	877	Highly active
Potassium ...	62.5	758	Highly active
Lithium ...	186	Above 1400	Active
Mercury ...	— 39	357	Inert
Cadmium ...	321	778	Very slightly active
Zinc	418	918	Slightly active
Argon ...	—188	—186	Inert
Krypton ...	—169	—152	Inert
Xenon ...	—140	—109	Inert

The comments given in the table under the heading "Chemical Reactivity" refer to the reactivity of the element in question with normal glasses or with

quartz, and with the other materials likely to be used inside electric discharge lamps, e.g., refractory metals, alkaline emissive oxides, etc.

Obviously an element must exert an appreciable vapour pressure at a temperature well below the softening point of known transparent refractories before it can be considered as a potential source of light in an electric discharge lamp. This means that in lamps with glass envelopes a useful vapour pressure must be developed below a temperature of about 600 deg. C., the corresponding temperature in the case of transparent quartz being about 1,000 deg. C. These criteria limit the possible materials to quite a small number. Furthermore, certain metallic elements particularly those of the alkali and alkaline earth metal groups are extremely electro-positive and very reactive chemically. For example they attack most glasses and cause surface discoloration or even complete disintegration if the temperature is sufficiently high. Sodium is a classical example of a metal possessing these properties. It is interesting to recollect that the sodium lamp owes its existence in a practical form to the development of a glass highly resistant to the attack of sodium vapour and to methods for using this glass as a glaze on the inside of more stable tubing.

It is thus evident that the choice of the most suitable transparent material

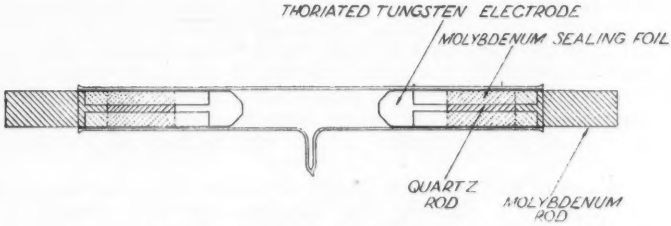


Fig. 1. Sketch of original Gas Arc lamp.

for the envelope is conditioned not only by its physical behaviour but also by its chemical properties. Some glasses gradually discolour under the influence of the electric discharge through certain vapours and this discoloration may result either from ionic bombardment or from direct chemical attack. Similarly the material of which the lamp electrodes are composed may be affected by elements which would otherwise be suitable as sources of vapour in the electric discharge lamp. The electron emission of an alkaline earth oxide electrode may be seriously reduced in the presence of the vapours of some elements, and the development of a successful lamp may depend on the production of a modified electrode to suit the chemical reactivity of the vapour component of the discharge.

These various examples are given to illustrate the fact that in considering the design of an electric discharge lamp, account must be taken of many factors all of which play some part in influencing the final result. The ideal to be pursued is of course a discharge lamp with an envelope consisting of a transparent refractory which will remain completely unchanged under the influence of the discharge, electrodes which suffer little or no sputter or evaporation during life, and a gas or vapour filling which emits its full light output of daylight quality and at high efficiency immediately the lamp is switched into circuit. The effect of some of these factors in determining the design of the Gas Arc will now be described.

(3) Consideration of a Practical Gas Arc Design

(3.1) General

Factors such as those already discussed suggested that exploration of the radiation characteristics of the inert gases at high current density was likely to prove fruitful. In any case it was likely to yield important additions to our knowledge of the behaviour of the rare gases under conditions of high excitation even if a practical lamp form did not emerge. The basic problem was to evolve a design of lamp in which a continuous arc could be produced at higher current densities than had been previously explored. Preliminary experiments on lamps similar to the high pressure mercury M.E. type but filled with inert gases did not at first yield important practical results; this was probably due to a combination of causes of which an important one was that the ionised gas was free to expand into the outer zones of the bulb remote from the inter-electrode space. It was found that a constricted discharge occurred in krypton and xenon at quite low pressures. The effect is related to the high atomic weights and low mobilities of these elements. Its occurrence suggested that it would probably not be necessary to exceed a pressure of a few hundred millimetres of gas to enable quite high current densities to be obtained in the Gas Arc. Such a constricted discharge however tends to be very mobile, and difficult to control.

It was therefore considered necessary for the practical attainment of a stable discharge that the arc itself should be closely confined and that convection currents set up in the gas should be restricted as far as possible by the envelope design. Such considerations suggested the use of a lamp of tubular form and of comparatively high loading. As current densities of the order of several hundred amperes per square centimetre were in mind it was thought that at gas pressures up to one atmosphere the arc voltage drop per unit length was likely to be low.

A lamp design of the basic form shown in Figure 1 therefore suggested itself and it was considered that the first experimental lamp should be made suitable in respect of the arc tube bore, the electrodes and the seals for carrying currents up to 200 amperes. At quite a low voltage gradient of say 10 volts per centimetre this current would lead to a loading of 2,000 watts per centimetre of arc length—a high value for a tubular lamp.

(3.2) Containing Vessel

The general considerations outlined above made it clear that the only practical material for the containing vessel would be quartz. A calculation showed that a quartz tube 20 centimetres in length and 1 centimetre in diameter would be needed for a dissipation of 1 kw. and that these dimensions would be consistent with an arc tube temperature of about 1,000 deg. C. This latter value is the maximum temperature which it is considered that a quartz tube will successfully withstand without the risk of devitrification or other softening or strain changes likely to lead to premature failure. On this same basis a 10 kw. air-cooled lamp would require a tube about 4 centimetres in diameter and 40 centimetres long. It was considered that in such a wide tube the arc would not be sufficiently controlled by proximity of the tube walls and that it would therefore be unstable due to the influence of convection currents. A longer, narrower tube, for example a tube 1 centimetre in diameter and 200 centimetres in length, would lead to a geometrical form which would require a very high voltage and therefore a relatively low current arc instead of the high current arc which was contemplated. It therefore appeared necessary to consider forced cooling of the lamp either by an air blast or by a water-cooling arrangement.

As various other water-cooled discharge lamps had already been developed

many of the problems were known and extrapolation from existing data was therefore possible. This revealed the fact that a 10-kw. water-cooled Gas Arc lamp could be contained within a quartz tube 15 millimetres in diameter and with an arc length between the electrodes of the order of 12-15 centimetres only. This data subsequently proved reliable and formed the basis for the first experimental Gas Arc lamps.

(3.3) Electrodes

A considerable amount of data on electrode designs had been obtained prior to the present investigation. Among other things it had been ascertained that in the high current density gas or metal vapour arc the cathode emission could not be wholly accounted for as pure thermionic emission and that field effects must predominate. In a well designed low evaporation electrode the cathode spot area was remarkably small and operated at current densities of the order of perhaps 100 amperes per square centimetre. The function of the main mass of the cathode was therefore to conduct heat away from the cathode spot area and so to prevent undue evaporation. Actually in a solid metallic cathode such as is used in high current density high-pressure mercury vapour lamps, slight electrode evaporation generally occurs in the region of the cathode spot, but the evaporated material redeposits on adjacent areas of the cathode. These changes which occur during the life of the electrode result in the gradual development of a characteristic granulated appearance. The temperature at the cathode spot should approach the melting point of the metal, and for high-pressure mercury vapour arcs tungsten containing about 5 per cent. thoria had been found by the author and his colleagues to be the most suitable material ([12]). With an electrode of this type, i.e. a solid thoria loaded tungsten rod, it has been found unnecessary to employ any alkaline earth emissive core or coating. Notwithstanding this fact the thoria loaded electrode has a very low cathode fall and will pass heavy currents without appreciable sputter. Viewed in retrospect this result is of considerable interest because for very many years the development of electric discharge lamps in their present compacted highly efficient forms was retarded due to the lack of a suitable electrode. For low-pressure high voltage discharge tubes plain cylindrical metal electrodes were generally employed and these were suitable only for quite low current densities of the order of a few milliamps per square centimetre. The application of Wehnelt type electrodes in which a refractory metal coil was either coated with or contained a core of alkaline earth compounds gave a low loss device capable of carrying several amperes. As development work proceeded it became desirable to operate lamps at still higher currents, and the alkaline earth oxide type of electrode became unsuitable owing to the evaporation of the activating material at the higher electrode temperatures which occur in high-pressure discharge lamps.

It was then found that plain tungsten rods could be used to form the electrodes of low voltage, high current, high-pressure mercury vapour discharge lamps, but that significant evaporation sometimes occurred. This led to the development of the thoriated cathode which was first applied by the author to short arc mercury lamps in 1937, and investigations covered tungsten thoria mixtures ranging from 0.5 per cent. ThO_2, up to 10 per cent. ThO_2. It was found advantageous to use the highest possible thoria content consistent with suitable mechanical working properties for the tungsten, and at 5 per cent. ThO_2 a convenient compromise was obtained. With higher percentages of thoria the grain boundaries in the sintered tungsten bar were weakened to an extent which tended to cause fracture of the material in the subsequent swaging processes

necessary for the production of a coherent electrode rod. Good coherent tungsten can, however, be produced with thoria loadings up to 5 per cent. by weight, and electrodes of this material have been operated in short arc mercury vapour lamps at cathode spot densities probably exceeding 10^5 amperes per square centimetre. In practice it has been found that several active cathode spots are produced in a localised area of the cathode, and that they emit simultaneously during the discharge. With increased current in the arc the number of these emissive spots increases, and there are therefore some grounds for suggesting that each spot may carry a similar maximum current. Further investigation is necessary to elucidate this point. The nature and pressure of the gas or vapour filling has also an influence on the electrode behaviour.

With such a background of experience it was decided to use for the first Gas Arc lamps electrodes of the thoriated tungsten type free from alkaline earth activation and to shape the electrode tip to concentrate the arc on to a very small area. The reasons behind this design were twofold:—

(1) To raise the electrode tip to a temperature near the melting point as quickly as possible after the discharge was initiated.

(2) To centre the arc in the containing tube and so to prevent it wandering into contact with the quartz wall.

With regard to this second point it was considered that if the arc was brought into contact with the quartz tube in the vicinity of the electrode then melting of the quartz would be inevitable, even if the tube was water-cooled.

The next essential feature was to prevent the electrode from overheating, and as it had already been decided to water-cool the quartz tube in which the discharge was to take place, the electrode dimensions were chosen to allow also some cooling of the electrodes. The lack of such provision would result in the need for larger electrodes and more complex constructional methods than those contemplated.

(3.4) Construction and Sealing Methods

The general techniques developed in this country for the direct hermetic sealing of molybdenum conductors through quartz have been described in previous publications.[1, 2, 3, 4, 6] In the case of the Gas Arc the conducting member employed for the early experimental lamps consisted of a specially prepared molybdenum sheet bent into cylindrical form. The molybdenum cylinder was not quite complete, as it was designed to cover only about 350 deg. of arc, the opposing edges being feathered away to less than 20 microns in thickness. This sealing member embraced the rear portion of the electrode, in the manner shown in Fig. 1, and was itself embraced by a second cylinder of heavier molybdenum sheet to form the current carrying conductor exterior to the lamp. As the completed seal and electrode assembly were both designed to be water-cooled it was found possible to employ a very compact arrangement. For example, a complete seal to carry 150 amperes was only 12 millimetres in diameter and 20 millimetres in length.

In constructing the lamp, the electrode assembly complete with sealing member was mounted inside a quartz tube, and the molybdenum foil cylinder was supported on a second quartz tube closed at the end adjacent to the thoriated tungsten electrode, against which it abutted. The outer tube after evacuation was collapsed both on to the molybdenum cylinder and part of the electrode leading to the finished lamp form, as shown in Fig. 2. This illustration shows the first successful lamp after the pieces of quartz used in the evacuation process had been removed and after the subsequent exhaust and gas-

filling procedure. This lamp was operated successfully at 10 kw. for short periods, and for several hours at 7.5 kw. It was the prototype for a series of experimental lamps made with different gas-fillings. These early lamps were constructed with various diameters of tubing and arc lengths in order to determine the optimum dimensions for a given loading. It is interesting to note that as a result of this work the original calculations were found to have led to approximately the optimum design.

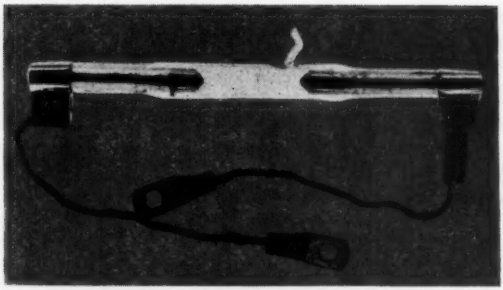


Fig. 2. The Gas Arc lamp.

(4) Gas Arc Characteristics

(4.1) General

The value of a new light source may be assessed by the extent to which it emits radiation of desirable quality, quantity and concentration. A new source may be useful in comparison with existing sources if it is improved in any one of these characteristics. If it combines improvements in two or more sections it may become important in several fields of application. The properties of the Gas Arc will be considered in relation to these several methods of assessment.

(4.2) Luminous Characteristics: Introductory

It will be helpful to view in retrospect one of the reasons which led to the studies that eventually produced the Gas Arc. This reason was the colour of the radiation produced by the so-called flash discharge tubes with argon, krypton or xenon fillings. It will be remembered that flash tubes generally operate under short circuit conditions when connected across the terminals of a charged capacitor after being rendered conductive by a suitably timed ionising pulse. Their design, operation and application have been described before this Society and elsewhere. [1, 14, 15] We are concerned at the present, however, only with their luminous characteristics.

It was found several years ago that if the current density in the flash discharge was sufficiently high a white light was produced with any of the above-mentioned gas fillings. An analysis of this apparently white light revealed the fact that with each gas a very complex line spectrum was dominated by an intense continuum of radiation extending from the remote ultra violet through the visible spectrum up to at least 11,000 Å in the infra red. The white colour was therefore not due primarily to the happy coincidence of complementary spectral lines but was due to the similarity of the flash discharge spectrum to that of an incandescent body. Here then was a way of producing a white light through the medium of a gas discharge which would have colour rendering properties similar to those of daylight. Actually it was found that the flash discharge through argon, krypton or xenon was always slightly more blue than that of an incandescent body at temperatures up to 6,500 deg. K. This is an important observation in view of the results subsequently obtained with

the continuously burning Gas Arc. For in this latter lamp, notwithstanding the fact that the current densities generally employed are about an order less than those at the flash discharge peak, the spectral distribution more nearly approaches that of sunlight.

(4.3) Colour

The colour of the radiation from the Gas Arc has been assessed in a variety of ways:—

(1) By direct determination of the C.I.E. co-ordinates.
(2) By measurements of the visible spectral composition.
(3) By visual comparison of the colour appearance of test objects.
(4) By colour photography.

In each case observations obtained with the xenon Gas Arc were found to resemble these obtained with sunlight. The quality of light emitted by argon and krypton under Gas Arc conditions is very little different from that of xenon. A neon filled Gas Arc lamp gives an interesting pinkish-white light which approaches more nearly to daylight as the current density is increased.

(4.3.1) *C.I.E. Co-ordinates*

The colour of light from Gas Arcs with a variety of fillings has been measured on the Trichromatic Colorimeter developed by Harrison. [17] Some typical results are given in Table 4. Data for two standard illuminants are also given for comparison purposes.

Table 4.

Typical C.I.E. Trichromatic Coefficients for the Gases Argon, Krypton and Xenon under Gas Arc Conditions.

	x	y	z
Xenon	.336	.334	.330
Krypton	.338	.323	.339
Argon	.309	.288	.403
C.I.E. Illuminant B.	.348	.352	.300
C.I.E. Illuminant C.	.310	.316	.374

(4.3.2) *Spectral Composition*

The spectral distribution has been measured in the eight spectral bands which have been standardised in this country for the assessment of the colour composition of light sources. The instrument used was that originated by the author in 1936 and subsequently improved by Harrison. [17] In the latest instrument a pure spectrum from the source under investigation is caused to fall on eight rectifier type photocells so dimensioned and positioned as to cover the visible spectrum in each of the agreed eight bands. For example, the first cell will have a width equivalent to the spectral range 4,000 Å to 4,200 Å ; the second cell 4,200 Å to 4,400 Å and so on.

The results obtained from such measurements are expressed as percentages of the total luminosity in the visible region 4,000 Å to 7,000 Å. Some typical data are given in Table 5. It will be seen that very close approximation to the colour of daylight is obtained from the xenon arc. The full spectrum is reproduced (Figure 3) to show its complexity and the intensity of the continuum

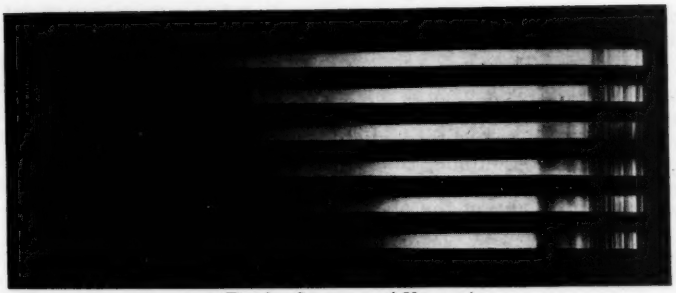


Fig. 3. Spectrum of Xenon Arc.

Spectrograms taken on Hilger medium quartz spectrograph on Kodak III L plate. Slit 0.05 mm wide, 5 mm. long. Exposure times as shown.

in the ultra violet, visible and infra red regions. The main departure from the spectral distribution of daylight is at the red end where the Gas Arc is comparatively more rich in radiation.

Table 5.

Typical Spectral Distribution Values for the Gases Argon, Krypton and Xenon under Gas Arc Conditions.

Waveband.	Percentage Luminosities.			
	Xenon.	Krypton.	Argon.	C.I.E. Illuminant C.
1. 4000–4200 Å ...	0.021	0.02	0.042	0.0248
2. 4200–4400 Å ...	0.21	0.30	0.42	0.266
3. 4400–4600 Å ...	0.70	0.74	0.98	0.910
4. 4600–5100 Å ...	10.9	9.5	11.6	11.14
5. 5100–5600 Å ...	38.7	38.2	40.7	40.88
6. 5600–6100 Å ...	36.0	37.5	32.0	36.14
7. 6100–6600 Å ...	12.4	12.6	12.7	9.96
8. 6600–7200 Å ...	1.05	1.09	1.6	0.726

(4.3.3) *Visual Comparison*

In assessing the value of a near white light source the eye is an important arbiter. The colour atlas issued by the British Colour Council forms a valuable comparison medium from which the appearance of different coloured materials may be compared under daylight and under the illumination from artificial light sources. This method was employed with the Gas Arc, and comparisons were made both with daylight from a north sky and with sunlight. Detectable differences were subtle and occurred on only very few of the numerous test colours in the atlas. One of the most sensitive visual comparison tests is that of the human complexion, and in the opinion of a

number of observers skin colour and texture under the illumination of the xenon Gas Arc is indistinguishable from its appearance under sunlight.

(4.3.4) *Colour Photography*

Photographic comparisons have been made with test subjects illuminated in turn with the xenon arc, with daylight, and with various other artificial light sources using Kodachrome, Dufay-Colour, and the Technicolor process. In each case it has been found that the light of the Gas Arc is very suitable for colour photography by any of the above processes.

(4.4) Luminous Efficiency

The development of a high efficiency from the Gas Arc occurs simultaneously with the development of the characteristic spectral continuum. With certain of the rare gases the highest efficiencies are obtained at quite low gas pressures, and with increase in the gas pressure the efficiency tends to fall. In investigating these phenomena it was found that with some gases there was a well-defined minimum in the efficiency/pressure and efficiency/current characteristics for several of the rare gases, and that beyond this minimum value the efficiency tended to increase with both increased gas pressure and increased current. These results are considered to be important as pointing the way to still further developments in the Gas Arc field. Some typical data are given in Fig. 4, which shows the luminous efficiency of krypton and xenon arcs over a range of operating conditions. It will be seen that the particular krypton arc under test had an efficiency of 20 l./w. at 5 kw. A similar lamp filled with xenon operated at 30 l./w. when loaded to 5 kw.

In comparing the efficiency of light production in absolute terms one cannot, of course, ignore the colour, although from the user's standpoint it is luminous efficiency which is important. From the lamp development point of view it is interesting to consider what would be the efficiency of a hypothetical Gas Arc if the radiation, instead of being fairly evenly distributed

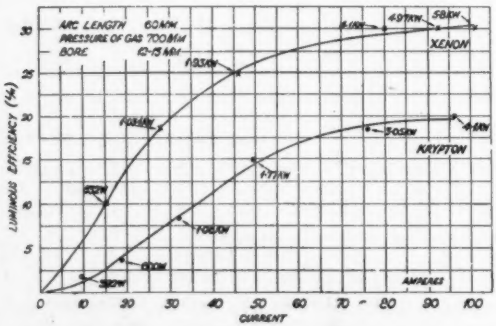


Fig. 4. Typical relation between luminous efficiency and current under Gas Arc conditions.

over the visible spectrum, was concentrated at some fixed comparison wavelength; for example, that of the sodium doublet. On such a basis the luminous flux from the xenon 5-kw. Gas Arc is equivalent to an efficiency of 60 l./w. at 5,890 Å. Such a method of assessment is commended to research workers as a means for comparing sources with widely different spectral composition, although it must be emphasised that it is of no practical value from the user's standpoint. The figure of 25-30 l./w. for the 5-kw. Gas Arc is the relevant

figure from the point of view of applications. In this connection it is interesting to remember the figure of merit comparison techniques suggested by Davies, Ruff, and Scott. [18]

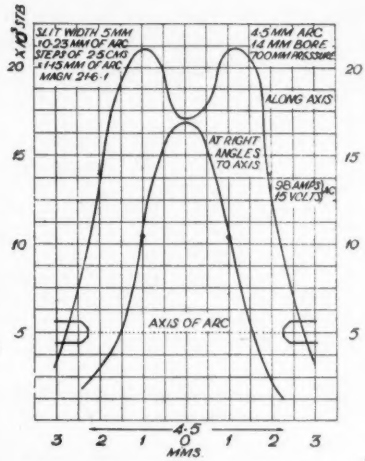


Fig. 5. Typical brightness distribution across concentrated Gas Arc.

(4.5) Brightness

Brightness distribution measurements have been carried out for the xenon Gas Arc operating at various loadings. The results shown in Fig. 5 for a 1.5-kw. Arc were taken along the axis of the Arc and across it at a point midway between the electrodes. The peak brightness is about 2×10^4 stilb. These results were obtained on a concentrated Gas Arc of the type shown in Fig. 10.

The centre arc brightness of the 5-kw. Gas Arc, however, with a loading of 1 kw. per centimetre of arc length is of the order of 5×10^3 stilb. It will thus be seen that the brightness of the Gas Arc is intermediate between that of the tungsten filament lamp and that of the high-intensity carbon arc. Some comparative brightness data are given in Table 6.

Table 6.

Source.	Brightness Stilbs.
Tungsten filament projector lamps	1,000 — 3,000
M.E. Lamps	20,000 — 60,000
Carbon Arcs	10,000 — 80,000
Gas Arcs	5,000 — 20,000

(4.6) Electrical Characteristics

The following data were obtained on lamps of the type so far described, i.e. Gas Arcs in which the ionised gas was confined within a comparatively restricted space between the lamp electrodes. Some characteristic curves are given in Figure 6 from which it will be seen that in the region A—B an increase of current brings about a decrease in the voltage drop between the electrodes. In the region B—C, however, further increases in current result in a steady increase in the lamp voltage, i.e. the arc characteristic changes at the minimum voltage given at point B and after first being strongly negative becomes positive. It is important to note that this increase in arc voltage is probably not due to electrode effects as it is associated with a steady increase in the efficiency of light production. The point at which reversal of the characteristic occurs is however conditioned by the lamp design as well as by the nature of the gas filling. Under any conditions so far investigated no positive characteristic has been obtained with helium. This fact is probably related to the high mobility of the helium ion compared with that of the ions of the heavier gases.

For all the other gases so far investigated the characteristic inflection in the

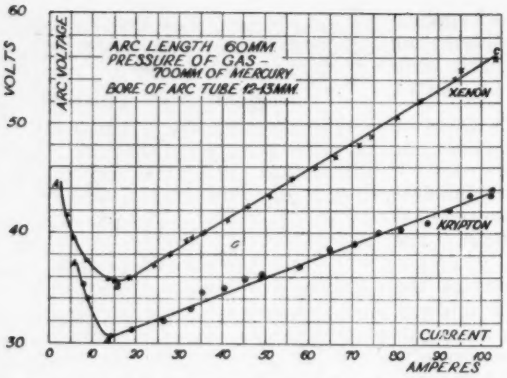


Fig. 6. Typical current-voltage relations for xenon and krypton under Gas Arc conditions.

current-voltage relationship is obtained and in each case the development of the intense arc continuum is associated with the region of positive characteristic.

(4.7) Life and Lumen Maintenance

The declared life of any electric discharge lamp can only be ascertained as a result of a considerable number of lifetests of a standardised type. Sufficient data are not yet available to enable the life of the Gas Arc to be stated with any accuracy. Five-kw. water-cooled lamps have, however, been operating successfully for periods in excess of 100 hours and in some cases satisfactorily up to 500 hours. From a general experience of discharge lamp developments it would therefore appear that there is a reasonable expectation of a life of about 100 hours and that this life value might be considerably exceeded for some lamps and generally as experience grows.

With alternating current lamps electrode sputter during life is remarkably small and the lumen maintenance is high. With lamps designed for direct current operation some gradual darkening at the anode end occurs during life. The effects, however, are not dissimilar to those met with in other types of highly loaded electric discharge lamps. No reliable data are as yet available to enable actual values for lumen maintenance to be given.

5. Lamp Operation and Circuits

(5.1) General

All the data so far given are independent of whether the arc is produced from direct or alternating current supplies; at least no measurable difference in efficiency or colour is obtained whether the arc is operated on a 50-cycle alternating supply or on direct current. No data are as yet available for high current operation at frequencies greater than 50 cycles per second. It will have been noted from earlier sections that the Gas Arc is essentially a low voltage high current device. The voltage drop per centimetre of arc length is of the order of 10 volts per centimetre and the current density across the discharge section is of the order of 200 amps per square centimetre. These facts enable the nature of the circuit problems associated with the operation of the lamp to be appreciated.

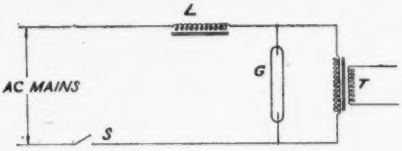
(5.2) Alternating Current Operation

A Gas Arc designed to have a lamp voltage drop of the order of 70-100 volts may be operated from either 110 volt or 200-250 volt A.C. mains. The current can conveniently be limited to the desired value by a series choke. The only problem is to secure ignition of the lamp.

Because of the relatively high gas pressures employed in the Gas Arc, which

may lie between 100 mm. of mercury and several atmospheres, a voltage of the order of 2 kv. may be necessary to produce the ionisation required to initiate the main discharge. This voltage can be applied from the output terminals of a suitable strayfield transformer connected as shown in the diagram below. Fig. 7.

With a circuit of this type the ionising arc may be left on for about 1-2 seconds before the main switch is closed. On closing the main switch the full



L. Series chokes.
S. Main switch.
G. Gas Arc.
T. Strayfield Transformer.

Fig. 7. Suitable circuit for operation of Gas Arc Lamp.

arc current passes and full light output is obtained at once. No appreciable changes in the lamp characteristics occur once the full arc current is flowing. The voltage and current wave forms for a typical xenon arc are shown in Fig. 8.

(5.3) Direct Current Operation

For operation on direct current supplies it is only necessary to substitute a resistance for the reactance used for A.C. operation. To obtain the optimum results, however, it is also desirable to modify the lamp electrodes as the anode tends to reach a higher temperature than the cathode. It is interesting to record that Gas Arc lamps have been operated on direct current mains without any limiting resistance in the circuit. The lamp current automatically regulates to a suitable value provided that in the design of the lamp the normal arc voltage has been adjusted to be of the same order as the applied voltage. With direct current operation the light output is, of course, completely steady and fluctuates only with changes in the input power.

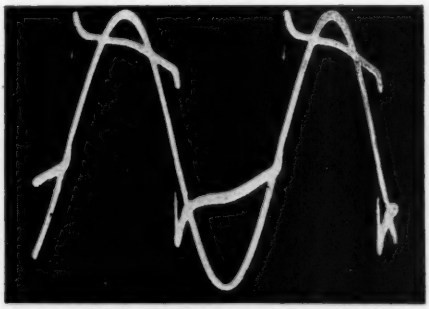


Fig. 8. Voltage and current wave forms for typical xenon arc.

An important characteristic of the Gas Arc is the fact that the arc current can be modulated over a considerable range without any serious change in the colour of the radiation.

(6) New Developments

(6.1) Other Gas Arc Design Features

In earlier sections the fact that the first Gas Arc lamps were water-cooled has been mentioned, and reasons have been given for the choice of this

technique. It must be appreciated that the electrical and luminous characteristics of the Gas Arc are not a function of the water-cooling nor indeed of any conditions exterior to the lamp itself. The water-cooling method enables the highest loadings to be obtained with available transparent refractories such as quartz, and without it the optimum characteristics cannot at present be obtained The development of new transparent refractories of higher melting point than quartz will therefore open up this field of development still further, but for the present we are limited to transparent quartz as the most suitable refractory for the gas envelope and to water-cooling as the best means for enabling the highest loadings to be obtained. Interesting results have, however, been produced with other cooling methods, as will be shown later.(6.3)

Table 7.

Dimensions and Characteristics of Standard 5 kw. Gas Arc Lamp and Flow Jacket.

LAMP.

	A.C.	D.C.
Wattage...	5000	5000
Line voltage	200/250	100/250
Arc voltage	about 65	about 65
Arc current (amps.)	about 80	about 80
Striking voltage	about 3000	about 3000
Luminous efficiency (l./w.)	25—30	25—30
Overall length (mm.)	250±3	260±3
Arc length (mm.)	65±1	65±1
Maximum external diameter (mm.)... ...	22	22
Caps	Brass shell	Brass shell
,, diameter (mm.)	17	17
,, length (mm.)	25	25
Burning position	Horizontal or vertical	Horizontal or vertical Anode down

FLOW JACKET (A.C. OR D.C.).

Overall length (mm.)	250±1
Jacket holder	Special brass
,, ,, length (mm.)	30
,, ,, diameter (mm.)	27 (internal) 40 (external)
Minimum internal diameter of glass (mm.)	26

(6.2) Water-Cooled Linear Form Lamps

The latest types of water-cooled lamps are illustrated in Fig. 9. They are of 5-kw. rating, A.C. and D.C. respectively. The A.C. lamp, as shown, is mounted inside a water-jacket through which a stream of water is automatically circulated: alternatively, the water-jacket may be connected directly to the water supply mains. For a 5-kw. lamp the rate of flow should be of the order of five litres per minute.

Both terminals of the lamp are immersed in the water: this simple arrangement has proved effective owing to the low voltage across the lamp terminals

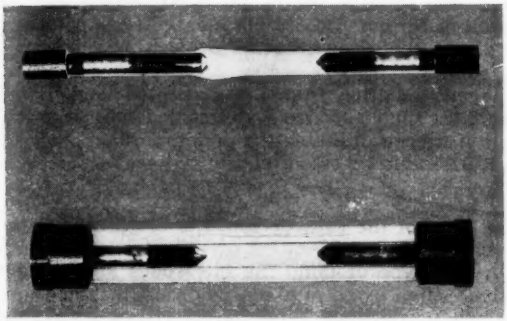


Fig. 9. 5-kw Gas Arc lamp.

Upper lamp for direct current operation. (Without water jacket.)

Lower lamp for alternating current operation. (Mounted inside a water jacket.)

when current is flowing in the arc. It also permits the use of quite thin flexible conductors to carry the lamp current, as the conductors may themselves be immersed in the water stream or may constitute some part of the water-circulating system, such as the entry and exit tubes to the lamp. In either case the conductor, by being water-cooled, has a low energy loss, and no difficulties have been experienced due to heating at the lamp connections, notwithstanding the heavy currents which are carried. Table 7 summarises some characteristics of the standard 5-kw. Gas Arc lamp.

(6.3) Air-Cooled Lamps

There are applications in which light of good quality is the essential feature and the efficiency of the source is not the most important factor. For these applications development work is proceeding on air-cooled linear forms of Gas Arc. For example, a 750-watt air-cooled xenon arc has the dimensions given in Table 8

Table 8.

Overall length	300 mm.
Diameter	14 mm.
Arc length	90 mm.
Arc voltage	49
Arc current	17 amps.
Efficiency	17 l./w.

Some measure of increased cooling to the seals and electrodes may be

Fig. 10. A concentrated Gas Arc lamp.

effected by the use of radiating fins. This type of lamp will operate in free air without any forced cooling and is a suitable source for floodlighting and for many projection purposes as well as for general illumination where a comparatively large light output of daylight quality is needed. Other air-cooled types are under development.

While the actual colour of the radiation from the air-cooled lamp is not quite so satisfactory as that from the higher-loaded water-cooled type, it is still sufficiently good for high quality interior illumination and for other purposes where good colour rendering is desirable or essential.

(6.4) Concentrated Gas Arcs

In the zone immediately in front of the cathode spot the brightness of the Gas Arc may reach values of 10^4 stilb. Consideration of this fact led to work on concentrated Gas Arcs. In this type of lamp the electrodes are brought sufficiently close together to give a high brightness source of small dimensions suitable for projection purposes in natural colour. The characteristics of a typical lamp are given in Table 9.

Table 9.

Arc length	4.5 mm.
Arc width	4.0 mm.
Arc voltage	15
Arc current	100 amps.
Peak brightness	20,000 stilb.

A photograph of one of these lamps is shown in Figure 10. It will be seen that the arc space is confined to prevent free circulation of the highly ionised gas. Other design features at present under investigation include modifications to both electrodes and envelope.

(7) Applications

(7.1) Introductory

In the development of applications for any new light source consideration must be given to such matters as:—

(a) Light output per lamp unit.
(b) Simplicity of operation.
(c) Efficiency.
(d) Colour.
(e) Advantages over existing sources.
(f) Life.

It is necessary for both the lamp engineer and the potential user to decide what benefits might accrue from the use of the new source and what difficulties

will have to be overcome. On the credit side the Gas Arc has the following characteristics:—

(1) Excellent colour.
(2) Cool light (due to water cooling).
(3) Immediate full light output.
(4) Fairly high concentration.

To obtain these advantages it is necessary to provide:—

(1) Water cooling.
(2) A momentary high voltage to procure ignition.
(3) A suitable current limiting reactance or resistance.

Of these necessary provisions (2) and (3) are common to many discharge lamps, particularly if full light output is to be obtained immediately the main circuit switch is closed. It should also be noted that many of the latest concentrated tungsten filament projection lamps require forced air cooling. With these facts in mind applications for the Gas Arc, without which the development cannot be fructified, may be considered.

(7.2) Studio Lighting

The luminous characteristics of the Gas Arc render it eminently suitable for photographic, film and television studio illumination. Work is proceeding on each of these applications.

In the case of Technicolor film applications a great advantage is the similarity of the radiation to that of Daylight. The radiation from the Gas Arc may therefore be used to supplement Daylight or to simulate Sunlight. In ordinary studio colour photography the subject may be illuminated to a very high intensity without the heating effects associated with other sources. The same remarks apply to television studio illumination.

Completely automatic circuits have been devised to switch on the water circulating pump, the starting voltage and the main power supply in proper sequence. One such arrangement was installed in the Science Museum, South Kensington, in May, 1948. A transportable Laboratory outfit including water-cooling arrangements, control panel and reflector is illustrated in Fig. 11. It will be seen that the water-cooling arrangements are suitably housed and that only two flexible leads are connected to the lamp housing. These leads carry both the water and the electrical supply.

Trials with Technicolor film have reached a point at which it can be reported that the colour rendering is indistinguishable from that of daylight. The fact that once the lamp is ignited no further attention is required and that a constant light output is obtained immediately, are notable advantages over alternative sources.

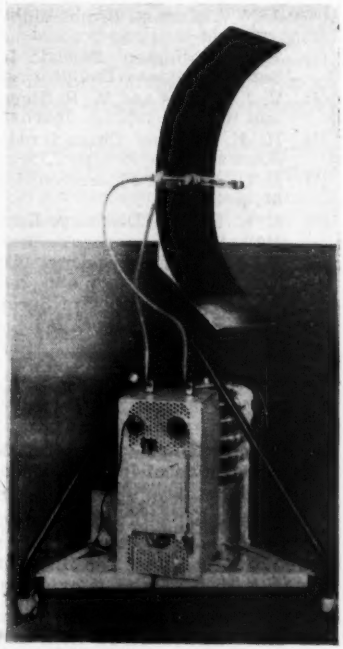


Fig. 11. Laboratory Gas Arc Unit.

(7.3) Special Applications

The Gas Arc is a powerful source of continuous ultra-violet radiation in the region 2800—4000 Å. Several photo-chemical reactions require intense radiation in this region and the Gas Arc is proving a suitable source.

As will be seen from Figure 3 the spectrum of the Gas Arc is also very rich in the infra-red region. It is, therefore, a powerful source of modulable infra-red radiation and its possibilities for certain applications in this field are under consideration.

(8) Conclusion

As stated in the Introductory section the object of this paper has been to discuss the evolution of the Gas Arc. To this end it was considered essential to confine the text to the broad lines along which the development has proceeded and to indicate certain possible lines for future development. It has not been possible to discuss the many interesting side issues which have arisen in the course of the work or to do more than treat the subject in a very general manner. Nor is it possible at this stage to predict with any degree of certainty what part the Gas Arc in its present or in any future form will play in the lighting field. The work to date has, however, opened up a number of interesting possibilities and like all new developments brought with it its own problems.

The author wishes to place on record his appreciation of the contributions made by his colleague, Mr. H. W. Cumming, B.Sc., A.R.I.C., in bringing the Gas Arc to its present state.

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Discussion

Mr. F. G. GUNN said:—

I should first like to acknowledge and thank you for the compliment you have paid me in inviting me here this evening to open a discussion on Dr Aldington's paper, but I should like to point out that my experience of lighting problems is confined to film production, and therefore all my observations will be made from that point of view.

The advent of a new light source is a matter of great interest to those of us who are concerned with the production of films, especially colour films.

The lighting of film sets is a very expensive business, as you will realise when I tell you that it is quite usual to find on a large set about 150 powerful arc lamps consuming in the aggregate some 2,000 kw. Apart from the capital investment in power plant, distribution system and lamps, the direct labour cost of operating staff, the cost of current, carbons and other consumable items, you have to reckon the consumption of everybody's time, particularly the highly paid artists, directors, etc., while the lights are being placed, adjusted and trimmed. Therefore, the direct and indirect cost of lighting a feature film must be considerable. So it is a subject that has always provided plenty of scope for the illuminating engineer.

My earliest recollection of studio lighting goes back nearly thirty years to the period immediately after the first World War. At that time, British studios were still using the old Westminster enclosed-flame arc lamp that was designed for street lighting, and hand-fed spotlamps designed for use in theatres. In fact, these were often referred to as "limes." About this time the Americans had made, and brought over to England, banks of Cooper-Hewitt low-pressure mercury vapour lamps, 150 amps. rotating positive high-intensity carbon arc lamps, made by the Sperry Gyroscope Company, and white flame arcs designed for diffused floodlighting. These were the first lamps designed specifically for film studio lighting, and film photography was greatly improved by their use.

For about ten years there was little change in the basic lighting equipment, although several manufacturers introduced lamps with detail improvements. These were the days when the director had to use a megaphone to make himself heard above the general din of studio activity and to shout instructions and cuts to the actors while the scene was in progress.

Then came sound recording, and with it a revolution in film studio lighting. The Cooper-Hewitt lamps with their ticking auxiliaries, and the carbon arcs with their splutterings, shrieks and groans, to say nothing of the noise of the operators moving around feeding them by hand, could no longer be tolerated. Fortunately, the lamp manufacturers had by then developed powerful metal filament lamps, and the film makers had perfected panchromatic emulsions which were ideally suited to these incandescent lamps. So the mercury vapour and carbon arc lamps were scrapped, and the studios went silent.

The incandescent filament lamp thus brought about the first big simplification of film studio lighting. The reduction in weight of the units, the elimination of trimming, and the remote control of large groups of lamps were all very big advantages which remain as worth-while objectives in any new technical development.

After enjoying the comparative tranquillity of this phase for a few years, the industry was thrown into another convulsion by the introduction of colour photography. The metal filament lamp was no longer an efficient illuminant. We wanted a source that would approximately match the colour of sunlight, so as to ensure the correct reproduction of colour in both interior and exterior

photography. Also, the lamps had to be very much more powerful. After careful experiment and development work an excellent series of carbon arc lamps were produced which were quiet enough to permit sound recording. These lamps have been the standard illuminant for colour films for the last 12 years, and they are also extensively used for black-and-white. Recently, further improvements have been made, and the exceptionally powerful and handy lamp, consuming 225 amps., which is now available, will take a lot of beating, and I am sure it has a long and useful life in front of it.

Nevertheless, many of the problems of lighting film sets remain to be solved, and we look hopefully to the newly developed light sources to help us with these. We have already seen the commercial application of the compact source mercury cadmium lamp which is now in daily use in the studios; but it is too early yet to say to what extent it will eventually replace the carbon arc and the incandescent lamp for special purposes. It has some excellent features, especially a very high efficiency, but it is so different from the older forms of illuminant that it may be some time before film cameramen use it with complete confidence. Now we have the Xenon Gas Arc, which Dr. Aldington has described and demonstrated. I am quite sure that most of us have already drawn up a kind of mental balance-sheet, and we are debating in our minds whether certain advantages will offset its disadvantages. For example, I think we may rest assured that the colour of the light leaves nothing to be desired, but we may not be quite so sure that the necessity for water cooling will not be troublesome.

Again, we must be wondering whether the lamp and its associated equipment will be perfectly silent, because at this stage of the development of studio lighting equipment we cannot tolerate even a little noise, which, when multiplied by the number of lamps in use, will result in an audible background. I should like to emphasise this, because the delays occasioned in film production by such parasitic noises can be very costly indeed.

The man who is going to make the lamp fittings to contain the gas arc will have noted that its efficiency in terms of lumens per watt is a little on the low side, and he will have to decide how he can offset this by utilising a greater proportion of the total light flux than is usually achieved in such fittings. He will also be concerned with devising so-called foolproof ignition circuits to avoid danger to operators or other equipment.

The cameraman, on the other hand, will, I think, seize upon the advantage of having a lamp which can be adjusted for intensity within quite wide limits without significantly affecting its colour, and this feature will, by the way, take care of one of the bugbears in some studios of very considerable fluctuations of supply voltage.

Looking a little ahead we might also find great advantages in the ability to run these lamps on alternating current. I have noted in foreign studios that the bulk of the supply to the set has been A.C., which was used for metal filament lamps with a small amount of D.C. supplied for operating just a few high-intensity arc lamps for sunlight and similar effects. Before such studios could embark upon colour photography they would have to install a very expensive A.C. to D.C. rectifier or generator system. The Gas Arc may provide at least a partial solution to this problem.

MR. H. R. RUFF said that the generic basis of the paper—light emission from high current density discharges through gases at high pressures—was a most interesting subject which lamp research laboratories had been studying for a long time but, as with similar discharges through vapours at high pressures,

the practical experiments seemed to be ahead of theoretical physical calculations. He asked Dr. Aldington if he did not agree that a further theoretical survey of high-pressure phenomena would help materially the experimental techniques which have to be followed at present and which are somewhat tedious and costly.

The paper was specifically concerned with the 5 kw. water-cooled xenon discharge lamp, which represented an interesting compromise between factors, many of which had been described. The author had suggested that this lamp was entering a new and most difficult phase, that of field trials. This very necessary phase in the development of any lamp was always rather a burden to the research workers, who had often to explain many times characteristics with which they were familiar, but at the same time had to avoid overlooking practical comments from users, which might make all the difference in guiding the development along practical lines.

It seemed to him that the success of this 5-kw. lamp would depend mainly on three considerations.

(1) Improvement in efficiency, possibly combining this improved efficiency with higher brightness.

(2) Proof of reliability.

(3) The development of what might, for want of a better term, be called "water-cooling engineering."

He commented on these points as follows:—

From calculations of efficiency, and referring particularly to Fig. 4, he said that the efficiency with which radiation was concentrated into the visible spectrum with such discharges seemed already to be fairly high. Some of the low practical efficiency was due to the low voltage drop of these arcs, bringing into prominence the question of electrode losses. Referring again to Fig. 4 it seemed to him that much of the lower efficiency of the krypton lamp might be due to the greater percentage of its electrode losses due to its lower voltage drop.

The point with regard to combining increased efficiency with higher brightness was that whereas the brightness figures in Table 6 referred to all sorts of sources, the higher brightness gas arcs were generally obtained by shortening the arc length, until when high brightness was obtained the luminous efficiency was low. He suggested the following peak brightnesses for 5 kw. sources:—

Tungsten Filament Projector Lamp	3,000	stilb.
ME Lamps	45,000	„
Carbon Arcs	70,000	„
Gas Arc	5,000	„

If the brightness of this latter lamp could be increased by 10 times, for a similar light-beam shape the lantern reflector dimensions could be correspondingly reduced. In its present form it was interesting to realise that from the cylinder of "incandescent gas" was obtained much the same efficiency and brightness as could be obtained from a cylinder of incandescent solid tungsten.

Proof of reliability under field conditions was, of course, a requirement for any new source.

He pointed out that the lamp designers had always been interested in water-cooling as a means for reducing lamp size, but that to date the balance generally swung back from water- to air-cooling after field trials. Water-cooled incandescent lamps had had a small field of application, but it was with the

introduction of the high-pressure mercury vapour lamp that a great deal of attention was focused on this development resulting in the standardising of 500-watt and 1,000-watt type MD/H projector sources. In the early days of mercury projector lamps a comparison of the size of water-cooled and air-cooled varieties seemed greatly to favour the water-cooled version, but in practice the great majority of the applications had required the use of the air-cooled lamp. While this was due partly to the extremes to which the quartz arc-tubes in these lamps had to be stressed, resulting in a rather random survival characteristic and short life, much of the preference appeared to have been due to the difficulties of providing water-cooling, and it seemed that much had still to be done in connection with "water-cooling engineering," concerning which the views of other members of the audience might be most helpful.

His own laboratory had been largely concerned with air-cooled gas discharge lamps, operating from pressures similar to those described to considerably higher values. This was one way in which higher brightness could be allied to reasonable efficiency. Such lamps might soon have some special applications. Their general use would require a practical solution of their own special operating and cost difficulties, but it seemed that once again we might see air-cooled and water-cooled types undergoing comparative field trials.

Mr. E. H. NELSON said that the gas arc had great theoretical as well as practical value, and he believed that a study of its characteristics would lead to a better understanding of the potentialities of gas and vapour discharges as light sources.

Development work on many types of highly loaded quartz lamps had now been going on for many years; and the lamp dealt with in Dr. Aldington's paper undoubtedly contributed much to this work.

There were a few technical matters which he wished to discuss: First, the efficiency of the lamp described by Dr. Aldington was rather low. Indeed, it was surprisingly low, having regard to the spectral distribution. He agreed with Mr. Ruff that a large proportion of the losses were due to wattage losses at the electrodes, but a further important loss was that due to conduction from the radiating gas to the cooling water.

This last factor, coupled with the complexity and inconvenience of water cooling, had led to the development of air-cooled lamps. He had been concerned with work on lamps of about 10 kw. rating, operating in spherical quartz bulbs some four inches in diameter, and burning in free air with no special cooling arrangements.

Such lamps revealed two particularly interesting features. The first was that, even at filling pressures of Xenon below one atmosphere, there was a high degree of constriction of the discharge, although it was quite unconstrained by the quartz walls of the lamp. This constriction meant high current densities in the discharge and consequently good colour and high efficiency. The second interesting feature concerned the instability of unconstrained arcs, which Dr. Aldington attributed to convection currents. It was quite true that the arc was unstable in such lamps, but there was a curious phenomenon associated with the instability. The instability seemed to originate at the lamp cathode and take the form of a powerful jet of gas expelled from the cathode. Similar phenomena had been observed in the carbon arc and the high-pressure mercury vapour lamp.

The instability appeared to be a specific phenomenon and gave hope that there was a specific cure. This being so, we should have a light source free from water cooling difficulties, and having good colour, high efficiency and,

probably, long life. At the moment the cost of filling a 10 kw. lamp with Xenon was very high—about £10—but, nevertheless, it appeared to be a very promising line of research.

With regard to the brightness of the gas arc, the outlook was not at the moment very encouraging. It was possible to obtain higher brightnesses by shortening the arc in order to increase the arc loading. This method, however, resulted in very considerable decrease of efficiency. It did not seem that brightnesses of the order of those achieved in the carbon arc or high-pressure metal vapour lamp were likely to be reached.

The positive characteristic was an interesting feature of the lamp as it enabled low values of ballast resistance to be used and so increased the overall efficiency of the lamp and equipment. How low the value of resistance could be made depended on the closeness of control of lamp wattage which was required. In the limit, when no ballast was used, the overall efficiency was fairly high, but the variation of lamp wattage with changes in supply voltage was likely to be too great for most purposes.

Finally, in considering lamp circuits, Mr. Nelson said that he had used a method of starting high-pressure rare gas lamps, both of the water-cooled and air-cooled types, in which a high voltage pulse was impressed across the lamp terminals in order to start the lamp. Such pulses were usually easy to generate and the necessary gear appeared to be less dangerous and lighter in weight than the high-voltage transformer used by Dr. Aldington.

PROF J. T. MACGREGOR-MORRIS said that it was at the opening meeting in October, 1935, he believed in the same room, that the super high-pressure mercury vapour lamp was exhibited. In those days the society had an annual exhibition of new developments in new lighting devices, and this lamp was shown, through the initiation of Mr. Sayers, by Professor G. B. Van den Werfhorst. The super-high-pressure mercury vapour lamp was shown in operation and also its spectrum. That was the first lamp he had seen which gave a practically continuous spectrum over the whole range of the visible part. The line spectrum was superimposed on it but was only faintly visible. That lamp required 1,250 volts per inch and the pressure in the lamp was about 136 atmospheres. The internal bore of the tube was of the order of one-eighth of an inch.

This super-high-pressure mercury vapour lamp had a drop in voltage of 500 volts per centimetre against 5.5 volts for the lamp which Dr. Aldington had described (Table 8) or 10 volts (Table 7) or 34 volts in the case of the Xenon concentrated gas arc (Table 9).

Continuing, he said he would like more information about the volt-ampere characteristics. According to Fig. 6, the pressure was about three-quarters of an atmosphere, and he asked whether this was the working pressure in the three lamps Dr. Aldington had described, particulars of which were given in Table 8. Was it to be inferred that it was 700 mm. mercury or did they operate at a higher pressure?

His other point was with regard to the static characteristics. It was generally known that when a lamp was working on A.C. circuits, the volt-ampere dynamic characteristic was not the same as its static characteristic. Therefore he had taken Fig. 8 in the paper and tried to work out the form of the dynamic characteristic from it, but only Dr. Aldington could fill in the amperes and volts as the scale was not given. As was to be expected it formed a kind of Hysteresis loop, increasing current giving the usual negative characteristic but yielding a positive one for falling current. He would like to

see this curve super-imposed on the static characteristic. It should give some indication as to how the lamp would operate at other frequencies and it might lead to suggestions for improvements in the lamp.

These dynamic characteristics can readily be obtained nowadays by means of a cathode ray oscillograph, instead of by the deduction from the wave-forms of the volts and amperes which is a relatively labourious operation.

MR. H. K. BOURNE said that he had found the paper very interesting from the point of view of one who was recently associated with the design of lamps and who was now more concerned with the design of lighting equipment in which they are used. In particular Dr. Aldington's claim that the gas arc had possibilities as a studio light source was most interesting. Its use in this field seemed to him to be limited at present chiefly by its relatively low efficiency which appeared to be but little higher than that of an incandescent studio lamp and far below that of a compact source lamp. Perhaps Dr. Aldington would give his views on the possibility of further increases in efficiency in the Xenon lamp which would enable adequate light output to be obtained from optical systems of reasonable size. Again, figures of life did not appear to compare favourably with those given by the compact source lamp. In particular it was to be hoped that the somewhat erratic life associated with the water-cooled high-pressure mercury vapour lamp was not also a characteristic of the water-cooled Xenon lamp. He did, of course, realise that some of the design troubles found with mercury lamps should be absent in the gas arc.

Absence of initial delay in warming up from the cold as compared with the compact source lamp was an important advantage of the Xenon lamp, although it should be remembered that the delay with compact source lamps could be reduced sufficiently for most practical purposes.

In spite of claims made for its good colour rendering properties he felt that there might still be a difficulty in this respect—not in the photographic rendering given by the lamp, which we knew was excellent, but in the visual appearance of colours illuminated by it. This difficulty would be apparent when the lamps were used in combination with carbon arcs on a studio set. Did not the Xenon lamp give somewhat more red than the carbon arc? If so, the cameramen would be faced with a problem in balancing up the set lighting when mixed sources were used. At present this difficulty was experienced with the compact source mercury cadmium lamp. When cameramen had had more experience of the new lamp the problem would, no doubt, be overcome.

Water cooling was an undesirable feature of the lamp. The engineering problems associated with the supply of water and electric power to the lamp could be overcome by applying the principles already used successfully in the studio with water-cooled carbon arcs. However, the water-cooled Xenon lamp imposed a further problem on the designer, viz., the problem of keeping the water clean. Failure to do this would lead to serious loss of light and change of colour of the radiation.

The fact that the lamp may be dimmed electrically without change of colour was another advantage, although Mr. Bourne doubted whether this was as important as appeared at first sight. The most recent method of dimming studio sources used D.C. "Selsyn" operated shutters on each lamp. These could be used for remote control of dimming with any type of light source without having to consider the question of colour change. This method of light control was fast becoming quite general in studios, and even though one out of the different types of lamps used on a set might be dimmed electrically it would

usually be found more convenient and economical to use shutter dimming on all the lamps.

MR. F. V. HAUSER said he had had the privilege of seeing this new lamp some time ago and had been impressed with the excellent colour. It at once appealed to him as a light source which would be used in film studios and what he had heard this evening had confirmed him in that view. However, he was still very dubious about water cooling, and had been pleased to hear that research was being carried out on this type of lamp as an air-cooled unit.

He felt a little critical of some of the remarks of previous speakers. Doubts had been expressed with regard to the efficiency of this lamp, but what was important was not the luminous efficiency but the efficiency of utilisation. Therefore, with a lamp having this remarkable colour and polychromatic spectrum, low efficiency was quite acceptable. He hoped, however, that it would eventually be possible to do away with water cooling. Mention had been made of the use of the water-cooled carbon arcs in film studios, but that was a special application. It was not used in direct motion picture photography and where it was used, it was a case of *force majeure*. Those concerned did not like it but they had to put up with it at present. However, he looked forward to the time when the new type of lamp could be used in considerable numbers, but the efficiency did not worry him because the main thing about set lighting lamps was ease of control and efficient utilisation. It was, no doubt, generally appreciated that most studio lamps were employed with an optical system and he looked forward to the time when the gas arc, air cooled, would be suitable for use in this way.

MR. A. CUNINGTON, referring to these lamps coming to the end of their life, said it would be interesting to know what happened. Was there complete deterioration of the whole fabric of the lamp, was it deterioration of the quartz tube only, or what part of the lamp was affected? He wondered what bearing the cooling might have and whether it was possible that some other method of cooling might increase the life of the lamp.

MR. C. R. BICKNELL, referring to the possibility of controlling the light flux of these lamps, pointed out that it is a common practice to mount a flood on each side of the camera, and to vary the light output from these as the camera is moved nearer to or farther from the subject. The fact that, with the gas arc, the light flux can be varied without alteration of colour quality would appear to make the lamp particularly suitable for such applications, particularly where colour photography is concerned.

MR. HAYS HALLETT, following up the point made by Mr. Bicknell, said that Mr. Gunn had mentioned the fact that some sets had as much as 20,000 amperes of lighting. It was a formidable engineering proposition to dim a current of that magnitude, and the remote control shutter was infinitesimal in size and cost as compared with resistances.

THE PRESIDENT said that since the main outlet for these lamps was in film studios, there was one aspect of the comparatively low efficiency which might have to be watched, which applied also to tungsten lamp equipment to some extent. The lower brightness efficiency of the arc might lead to units of large size, so that there might be difficulty in crowding lamps together when high illumination was required; for example, in "deep focus" photography in colour.

He congratulated the author on the small amount of noise from the water

circulating pump, but imagined that its design would need a good deal of care if trouble were to be avoided with a number of units running together. There was also the possibility of trouble due to deposit from the water on the water jacket, and some information on that point would be valuable.

DR. ALDINGTON, replying to the discussion, said he would deal briefly with the principal points, and amplify his answers in writing later.

There seemed to be a number of misconceptions. The efficiency had been criticised and compared with that of a tungsten filament lamp, but for colour photography the light from a filament lamp had to be filtered to give a colour comparable to that of the carbon arc. In such circumstances tungsten lamps gave an effective efficiency of only about six lumens per watt. The size of the gas arc unit demonstrated that evening had led to a further misconception. This unit was of a laboratory nature and relatively large, but if one removed the front cover and examined the actual lamp it would be found to be little larger than a penknife: there was no difficulty in associating units closely together. In that connection Mr. Hauser had put his finger on an important point. Dr. Aldington did not know the efficiency of utilisation of the carbon arc, but he suspected that it was quite low, whereas the unit he had demonstrated delivered 50 per cent. of the total flux of the lamp. When discussing the efficiency of any light source—and he had emphasised this many times at meetings of the Society—a lot more attention needed to be given to the efficiency of utilisation of the flux. Those on the lamp side did a great deal of work and secured improvements of 1 per cent. here and ½ per cent. there, but the people who used the flux just dissipated 50 per cent. here and 75 per cent. there! He did not know, for example, the efficiency of utilisation of a film projector, but he had heard that it was less than 10 per cent. This merely illustrated his general point that in discussing the efficiency of any light source the thing to take account of was how much power was used and how much light arrived on the work.

He had been very pleased to have the comments given by Mr. Gunn, and particularly his favourable report on the colour.

He entirely agreed with Mr. Ruff that this type of light source would benefit considerably by a fundamental investigation, particularly of a theoretical type, because we were concerned with orders of excitation, which had not previously been realised in a continuously burning gas arc.

With regard to brightness figures, it was necessary to examine the need for high brightness. The carbon arc was naturally a high brightness source, and the film studio lighting industry had grown round it because there was nothing else available until quite recently, but he completely failed to see why a very high brightness source such as the carbon arc was essential. If it were desired to project a light source in a parallel beam, then there must be high brightness, but for any of the functions he had mentioned the brightness of the gas arc was sufficient, and, in fact, a high brightness source was not necessary. Therefore, he could not agree that this new type of lamp should be criticised on the ground of its comparatively low brightness.

He was pleased to hear again—what he already knew—that this work had stimulated a considerable amount of research in other laboratories on air-cooled types of gas arc. In his firm's laboratories they were also continuing work on these types, and it was very helpful to have the various contributions which had been made and which he looked forward to seeing published at a later date.

A question had been raised respecting the relative efficiency of the krypton

and xenon arcs in relation to the total power dissipated in the arc itself and in relation to electrode losses. Mr. Ruff was quite right in his analysis of the position. Other things being equal in comparing two lamps if there was a lower arc voltage drop this was bound to lead to a lower efficiency relative to that of a lamp with a higher voltage drop. But there was an interesting comparison which he had made with the flash condition, where with high voltages and much longer paths, there was a remarkable similarity with the results obtained with the gas arc, i.e., about 50 per cent. increase in luminous efficiency for xenon-filled tubes, as compared with the same tubes krypton filled.

They had all been intrigued by the analysis which Professor MacGregor-Morris had made of the dynamic characteristic and static characteristics of the gas arc, particularly as the only material he had available was one or two cycles of current/voltage wave form. He would send Professor MacGregor Morris some data which would enable him to assign values to the calculations he had already made.

With regard to the suggestion that the camera man might experience difficulties caused by colour variations between the carbon arc, the mercury lamp, and the gas arc in combination, Dr. Aldington said that those who had worked with this lamp had not been able to detect any perceptible difference in the visual colour effect as between the carbon arc and the gas arc, but he believed there was some difference in the case of the mercury-cadmium lamp. However, the Technicolor people were able to overcome this difficulty by means of the three-tone process. An advantage of the xenon arc was that by any process so far used for colour photography it would give accurate colour rendering to daylight, and that was not true of possible alternative sources.

The engineering problems connected with water cooling were real, and the paper pointed out the advantages and disadvantages of water cooling. Although the "set-up," which had been demonstrated, was a laboratory and experimental one, no difficulty had been experienced with the water-cooling system. There had been neither serious deterioration of the light output nor deposit producing devitrification of the quartz, although on an earlier model which was placed in the Science Museum, there were some serious difficulties, due to electrolytic effects, which had resulted in the darkening of the quartz tube. These effects had been eliminated.

As to what determined the end of the life of the lamp, a point mentioned by Mr. Cunnington, two things might bring this about, namely, electrode sputter, which eventually affected the life and light output, or the decision, after examination, that the lamp had run long enough and ought to be replaced. This latter, however, was a feature common to all electric lamps.

Reference had been made by Mr. Bourne to the erratic behaviour of high-pressure mercury vapour water-cooled lamps, but nothing of that kind had yet been experienced with the gas arc. Here it was rather a case of "know how." It was easy to build a lamp of this type which would crack up and burst, or fail prematurely for other reasons, but it had been possible to overcome such difficulties with the gas arc, and at the present moment the life was mainly determined by electrode deposits.

Dr. Aldington said that he would not make any comment on the President's remarks except to thank him for calling attention to noise that did not exist! As a matter of fact, the cooling-pump motor was running in the demonstration apparatus during part of the lecture.

Further written reply by the Author.

A study of the report of the discussion shows that the points raised fall into two main categories:

(1) lamp operating characteristics;

(2) various aspects of application of the gas arc.

It is proposed to deal with these in this order.

Lamp Operating Characteristics

The question of efficiency of the gas arc had been dealt with fully in the discussion, but some further figures might be of interest. To correct the colour temperature of a filament lamp operating at 2,848 deg. K to a value of 6,500 deg. K involves the use of a filter having a transmission of 15.5 per cent. and hence it can be seen that the figure quoted of 6 lumens per watt for the overall efficiency of a tungsten filament lamp plus filter was somewhat higher than obtained in practice. It is, perhaps, not out of place to emphasise again the fact that where a quantity of light has to be directed on to a given area, efficiency of utilisation is the factor to which even more attention should be directed than to the intrinsic efficiency of the actual light source.

It has already been shown that the gas arc was eminently suitable without filtering for Technicolor "takes." In this connection the remarks of Mr. Gunn and Mr. Hauser confirming this point were most welcome. In Mr. Gunn's own words—"The compact source mercury cadmium lamp is now in daily use in the studios." Since the colour appearance of the gas arc is closer to the carbon arc than is that of the mercury cadmium lamp there can be no doubt whatever that the gas arc radiation will be acceptable for this purpose. An advantage of the Xenon arc, as already stated, is that by any process so far used for colour photography it will give accurate colour rendering compared with daylight.

Immediately on striking the Xenon arc full brightness may be achieved; this does not apply with the mercury cadmium lamp. It has been stated by one speaker that the run-up time for the mercury vapour lamp has been reduced to a sufficient extent for most practical purposes. It should be borne in mind, however, that a simple solution to this problem for the mercury cadmium lamp has only been achieved with lamps of comparatively low wattage, i.e., 2,500 watts. The normal practice with lamps of higher wattage is to allow energy to be dissipated in a suitably lagged oven surrounding the lamp envelope and when full light output is required the oven is removed and the arc current increased to its normal operating value. This method, of course, involves the continuous dissipation of energy in order to maintain the lamp in a condition ready for immediate use; it also requires the use of a high-voltage striking pulse to initiate the arc. These facts emphasise the advantage of having immediate full light output from the gas arc. Another very important factor which had, perhaps, not been sufficiently emphasised in the paper itself was the fact that the radiation from the gas arc was much cooler than that of any comparable known illuminant. Extremely high luminous flux densities could be directed on to a set without appreciable rise in temperature. This factor had already proved strikingly advantageous where high illumination was necessary for colour photography.

Regarding the very interesting comments of Professor MacGregor-Morris it may be stated that the working pressures within the gas arc have not been determined directly. The pressures given in the paper refer to a lamp at normal temperatures. During operation the pressure will be considerably over

one atmosphere, and values not exceeding five atmospheres may be expected. From experience of the design of high-pressure mercury vapour lamps one can estimate that the present 5 kw. gas arc construction would be suitable for withstanding operation pressures up to, perhaps, 10 atmospheres.

A study of both static and dynamic volt/ampere curves has been of considerable help in the development of other forms of discharge lamps, but as a large proportion of the work on the gas arc has been concerned with direct current operation its dynamic characteristics have not been closely studied up to the present time although it is realised that they would give some indication as to how the lamp would operate at higher frequency alternating currents. Since the reading of the paper these characteristics have been recorded and the two oscillograms shown (Figs. 12a and 12b) are for a gas arc lamp operating at 45 volts and 37 amperes. In the case of the dynamic characteristic the current form was applied to the horizontal plates and the voltage wave form to the vertical plates, the amplitude being the same in both planes. It is most

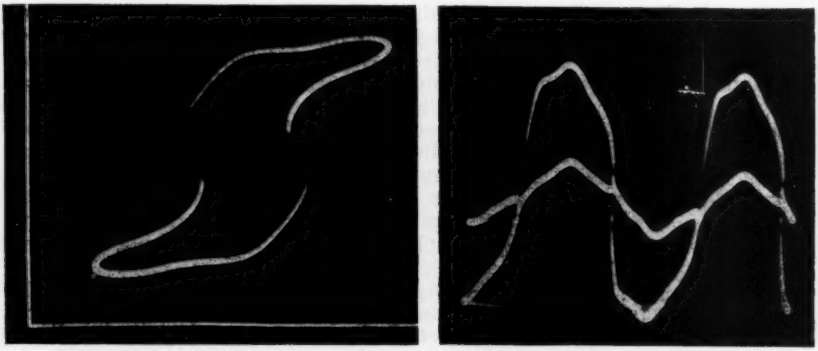

Fig. 12. (a) *(left)* Dynamic wave form; (b) *(right)* Static volt/ampere wave form.

interesting to note that the static wave form differs somewhat from that reproduced in the original paper. The general shape, of course, is similar but it can be seen that the new wave form gives unmistakable evidence of a considerably improved electrode design. In point of fact, the original figures were obtained with a lamp prepared in the early stages of the development work. It should also be noticed that the static wave form exhibits the positive resistance coefficient of the gas arc; instead of the wave form being "flat topped" as the arc strikes on each successive half-cycle, the curve tends to be dome-shaped, showing a rise of arc voltage as the current builds up to a maximum.

Dealing further with the positive resistance characteristic of the arc at higher current densities it may be stated that it is possible to operate two gas arc lamps, having similar arc voltages, in parallel directly across a given line voltage. It is true, however, that while the overall efficiency of the lamp and circuit may be increased by lowering in this way the value of series resistance, the supply voltage should not be subjected to variations, otherwise the luminous output will fluctuate.

Gas Arc Applications

Regarding the circuit for the operation of gas arc lamps it should be borne in mind that Fig. 7 illustrates a preferred arrangement and one which enables the basic requirements of the circuit to be appreciated. In this way

a lamp may be operated satisfactorily with a minimum of components. The arc can be initiated by ionising with either a Strayfield transformer or a simple pulse circuit. The latter, however, is more complex than the transformer method and involves a circuit containing components which cause it to be somewhat less reliable. Either method can be designed in a form to give a weight small in comparison with the total weight of the equipment. A Strayfield transformer moreover may be over-loaded for the short periods required to initiate the discharge, thus further reducing weight and size, but it does entail an A.C. supply giving several amperes. The transformer gives reliable starting whether the lamp is operated from either A.C. or D.C., whereas it is found that a pulse circuit tends to be less satisfactory on A.C. than on D.C.

Precautions should be employed, particularly in commercial applications, to ensure that equipment and personnel are adequately protected from the high voltage impressed across the lamp terminals immediately prior to the arc striking. The use of suitable capacitors will provide the necessary safety measures to give complete reliability.

The application described by Mr. Bicknell was based on an important characteristic of the gas arc, referred to in the paper; the light flux can be varied by modulation of the arc current without alteration of colour quality. Mr. Gunn has drawn attention to this point and has indicated the advantages likely to be derived and, therefore, it is somewhat surprising to learn that some speakers thought the use of remote controlled shutters would be more convenient and economical. Where the dimming involved one or two lamps only current control involving a maximum current of about 170 amperes would be by variable resistance; the possibility had also been considered of running the lamp from a separate generator with field regulation for current control. It was never intended that the full complement of studio lights should be dimmed by one control resistance.

While lamps of an air-cooled form will theoretically tend to give higher luminous efficiency due to the elimination of energy losses, in any practical design a balance must be reached between luminous efficiency and loading of lamp envelope to give a useful life. It would be of interest to know the order of efficiencies obtained with the air-cooled lamps of a spherical shape referred to by Mr. Nelson. A discharge through Xenon tends to be constricted due to the low mobility of the gas, but it is found in practice that the wall of the envelope plays an additional important part in limiting the movement of excited atoms thus giving an improved luminous efficiency. Work has been done on methods for forced cooling of the envelope using liquids of higher boiling point than water, e.g. ethylene glycol. The fact that the boiling points of suitable liquids were generally less than about twice that of water prevented any significant change in efficiency from being observed; there were, however, certain advantages to be derived, although these were of a different nature.

While development work is proceeding to enable more efficient air-cooled forms of gas arc to be prepared it is by no means certain that the water-cooled type will be superseded for all applications. For cinema studio lighting the air-cooled form of lamp, providing the colour is sufficiently close to the present water-cooled form of gas arc, will probably be preferred. The laboratory gas arc unit, as demonstrated, has a completely enclosed water circulating system in which the only sound producing component is a small motor-driven pump, enclosed in a simple sound reducing container. By further insulating this pump the quantity of background noise can be so reduced that even with the use of numbers of such units the total noise would not be objectionable. It

may be stated emphatically that there is no noise whatever associated with the actual flow of liquid. For some applications, indeed, water cooling of the lamp is an advantage, particularly where the water flows away to waste, in that unwanted heat can conveniently be removed from the lamp housing or associated equipment. Such advantages have been fully dealt with in the paper.

Regarding the new phase which this lamp is about to enter, i.e. that of field trials, the new lamp has already given indications that with suitably designed apparatus it is likely to give the necessary degree of reliability, but naturally, final proof will only come after extensive operation.

In conclusion the author would like to thank Mr. Gunn for his comprehensive and most interesting survey of the progress of electric lamps in the cinema studio industry.

Sessional Meeting in London

A sessional meeting was held at the Lighting Service Bureau, 2, Savoy-hill, London, W.C.2, at 6 p.m. on Tuesday, December 14, 1948, when the chair was taken by the president (Mr. J. M. Waldram).

The minutes of the last meeting having been taken as read and approved, the president called upon Dr. J. N. Aldington to present his paper entitled "The Gas Arc—A New Light Source." The author described the various stages in the development of this new light source and discussed its radiation properties. The Gas Arc was demonstrated to show the similarity of its radiation to daylight. The concluding sections of the paper dealt with some of the latest developments in the field of Gas Arc lamps and with possible applications.

After a vote of thanks, proposed by the president, had been carried, the discussion was opened by Mr. F. G. Gunn, who was followed by Mr. H. R. Ruff, Mr. E. H. Nelson, Prof. J. T. MacGregor-Morris, Mr. H. K. Bourne, Mr. F. V. Hauser, Mr. A. Cunnington, Mr. C. R. Bicknell, Mr. C. Hays Hallett, and the president. The author replied to the discussion and the meeting was closed.

Register of Lighting Engineers

The following applications for inclusion on the Register of Lighting Engineers have been accepted:—

J. A. H. Studholme, E. A. Langsdon, J. Mortimer Hawkins, C. T. Martin, L. Johnson, R. Pelerin, R. A. Hounslow, J. Watson, M. Gaughan, R. W. Stevens, H. D. Ritchie, G. S. H. Mogford, S. D. Lay, G. J. Everett, G. R. Hanson, G. E. L. Comrie, S. J. Cooper, R. E. N. Gamble, C. J. Hughes, S. E. Harris, L. E. Gibbs, S. L. Lyons, J. D. Ducker, H. Wilcock, R. S. Cantrill, A. M. Rankin, G. Eddison.

SESSION 1948-1949

Present Officers and Members of Council

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The Rt. Hon. the EARL OF MOUNT EDGCUMBE, T.D. (Fellow).
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Mr. W. J. JONES, M.SC. (Fellow).
Mr. R. O. ACKERLEY (Fellow).
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Mr. H. C. WESTON (Fellow).

Vice-Presidents :—

Dr. E. C. Walton, B.Eng.
Mr. E. W. Murray (*Fellow*).
Dr. J. N. Aldington, B.Sc., Ph.D. (*Fellow*).

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Mr. A. D. S. ATKINSON (1948)
Mr. H. S. BARLOW (1948)
Mr. C. R. BICKNELL (1947)
Mr. H. BRIGHT (1947)
Mr. L. J. Davies (1946)
Mr. G. H. GILES (1948)
Dr. H. F. GILLBE (1948)
Mr. C. E. Greenslade (1946)
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Mr. E. C. LENNOX (1948)
Mr. H. A. LINGARD (1947)
Dr. J. H. NELSON (1947)
Mr. A. J. P. Pashler (1946)
Mr. A. G. Penny (1946)
Mr. L. C. RETTIG (1948)
Mr. J. S. SMYTH (1947)
Mr. W. T. F. SOUTER (1948)
Mr. J. F. STANLEY (1947)
Mr. W. R. Stevens (1946)
Mr. P. CRAWFORD SUGG (1947)
Mr. S. G. TURNER (1948)
Mr. F. Walker (1946)

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Cardiff	—Mr. J. S. CHILDS
Edinburgh	—Mr. S. G. BATT
Glasgow	—Mr. D. ROSS
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Mr. J. G. Holmes (1948)

Hon. Secretary :—
Mr. H. C. Weston (1948)

Hon. Editor of Transactions :—
Mr. W. R. Stevens (1948)

The names in italics are those of Officers or Members retiring in 1949. The date in parentheses after each name indicates the date of election to Office or Membership of the Council.

ELECTION OF OFFICERS AND COUNCIL

SESSION 1949—1950 OFFICIAL NOTICE

IN accordance with the procedure specified in the Articles of the Society, a list of existing Officers and Members of Council, of vacancies occurring and of duly qualified persons nominated by the Council for vacancies about to occur in the offices of President, Vice-Presidents, Hon. Treasurer, Hon Secretary, Hon. Editor of Transactions, and Ordinary Members of Council, is presented below for the information of the Members of the Society.

In the event of any Members desiring to put forward other names, the Council will be pleased to receive such nominations, which should be made in accordance with the following rule (Article 48):—

> "After the issue of the Council's list, and not later than the *15th day of April* next following, any ten Members (but no more than ten) may nominate any other duly qualified person to fill any such vacancy by delivering such nomination in writing to the Hon. Secretary, together with the written consent of such person to accept office if elected, but each such nominator shall be debarred from nominating any other person for the same office at such election."

Nominated by the Council to fill Vacancies:—

***President*:—**

Mr. J. S. PRESTON, M.A. (Fellow).

***Vice-Presidents*:—**

Dr. J. N. ALDINGTON, B.SC., PH.D., (Fellow).
Mr. L. J. DAVIES, B.SC., M.A.
Mr. C. R. BICKNELL, B.SC. (Fellow).

***Members of Council*:—**

Mr. H. G. CAMPBELL
(Asst. Managing Director, The Benjamin Electric Ltd., London).

Mr. W. J. WELLWOOD FERGUSON
(Consulting Ophthalmic Surgeon).

Mr. C. A. HOSKINS
(Lighting Engineer, British Railways).

Mr. J. N. HULL
(Lighting Research Engineer, British Thomson-Houston Co., Ltd., Rugby).

Mr. A. W. JERVIS
(Consulting Engineer, Debenhams, Ltd.).

Mr. E. B. SAWYER
(Manager, Lighting Service Bureau, London).

Dr. W. S. STILES
(Physicist, National Physical Laboratory).

Mr. D. A. STRACHAN
(Lighting Engineer, National Coal Board).

***Representatives of Centres*:—**
(ex-officio)

To be appointed before October 1, 1949.

***Hon. Treasurer*:—**
Mr. J. G. HOLMES

***Hon. Secretary*:—**
Mr. H. C. WESTON

***Hon. Editor of Transactions*:—**
Mr. W. R. STEVENS

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

London Electricity Board.....*Representative*: F. C. Fenton.
46-7, New Broad Street, E.C.2.

CORPORATE MEMBERS:—

Arnold, R. F. .....24, Carlton Place, SOUTHAMPTON.
Ball, V. H. .....20, Marshall Grove, Erdington, BIRMINGHAM.
Banbury, J. .....23, Yarrell Mansions, W. Kensington, W.14.
Black, S. .....36, Hart Street, Henley-on-Thames, OXON.
Christy, D. R. .....1, Bloom Park Road, LONDON, S.W.6.
Clack, F. J. G. .....33, Northcote Avenue, Ealing, W.5.
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Dodson, G. A. G. .....16, Croft Road, Yardley, BIRMINGHAM.
Ferguson, E. C. .....1, St. George's Court, Five Ways, Edgbaston, BIRMINGHAM.
Furse, J. D. .....85, Costock Avenue, Sherwood, NOTTINGHAM.
Goslett, P. G. .....118, Wellesley Court, Maida Vale, W.9.
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Jackson, M. G. A. .....36, Sandringham Road, Watford, HERTS.
Jones, K. .....64, Hesketh Avenue, Rock Ferry, CHES.
MacLeod, D. .....c/o Revo Electric Co., Ltd., 30-1, Gt. Queen Street, Kingsway, W.C.2.
Mason, G. D. .....20, Beechwood Court, Carshalton, SURREY.
Pearson, R. B. .....140, Longlands Road, Sidcup, KENT.
Pollock, W. .....56, South Parade, Whitley Bay, NORTHUMBERLAND.
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Smith, R. N. .....7, Rosevale Road, Bearsden, DUMBARTONSHIRE.
Staniforth, N. L. .....127, Basegreen Avenue, Gleadless, SHEFFIELD.
Stewart, T. .....1100, Shields Way, Walkerville, NEWCASTLE-ON-TYNE.
Taylor, J. L. .....11, Sunnymead, Waterloo, Huddersfield, YORKS.
Tizzard, N. .....Tudor Court Hotel, 60, Cromwell Road, LONDON, S.W.7.
Wann, W. P. .....13, York Road, Acomb, YORK.
Ward, F. J. B. .....8, Greencliffe Drive, YORK.
Webb, A. .....159, Bradway Road, SHEFFIELD, 8.
West, G. E. .....50, Woodland Gardens, Isleworth, MIDDX.
Wotton, E. G. .....51, Bristol Road, LONDON, E.7.

STUDENT MEMBERS:—

Hardy, R. H. .....“Dalemoor,” Netherfield Road, Guiseley, LEEDS.
Prentice, J. W. .....“Clive House,” 23, Trafalgar Road, Newport, I.O.W.

I.E.S. Regional Committees
Session 1948—1949

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Groups:

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Printed by ARGUS PRESS, LTD., Temple Avenue and Tudor Street, London, E.C.4., England